BELLCOMM, INC.

SUBJECT: The Nuclear Reactor-Thermoelectric Power Subsystem - Case 103-2

DATE: November 9, 1966

FROM: J. D. Dunlop

ABSTRACT

The state-of-the-art of nuclear reactor-thermoelectric converter power subsystems is discussed in this report. The AEC has developed the UZrH SNAP reactors to a completely developed and demonstrated design for space flight applications. The preferred conversion unit for the SNAP reactors is the thermoelectric converter which has also been developed and demonstrated for space applications.

In the advanced design studies the estimated specific weight is from 2.0 to 3.0 watts/lb including shielding for man-rated systems ranging from 5 to 20 kilowatts. The range in power is obtained by varying the reflector size and the number of fuel elements. Lifetime capabilities of over three years can be provided with high reliability.

Based on the demonstrated operational experience achieved to date and the advanced design studies, it is reasonable to consider this type of system as feasible for a manned missions in the 1970's.

N79-73206

(NASA-CR-153786) THE NUCLEAR REACTOR-THERMOELECTRIC POWER SUBSYSTEM (Bellcomm, Inc.) 7 p

Unclas
00/73 12437

FACILITY FORM 602
~~X67-85580~~ (ACCESSION NUMBER)
(THRU)
(PAGES)
(CODE)
CR-81632 (NASA CR OR TMX OR AD NUMBER)
(CATEGORY)

[redacted]

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MEMORANDUM FOR FILE

A number of different power subsystems are being considered for the Mars manned flyby mission with the solar cell array providing the baseline power subsystem. Apparently the nuclear reactor-thermoelectric system is not being considered as a contender. A considerable effort by the AEC and its contractors has gone into the development of reactor-thermoelectric systems and components. The demonstrated results and expectations based on design studies of advanced systems are discussed in this report.

SNAP Nuclear Reactor

The only heat source which has been developed by the AEC for a multikilowatts electrical space power system is the UZrH SNAP reactor. This reactor uses fully enrichea uranium 235 as the nuclear fuel. This fuel is alloyed with zerconium hydride which serves as the moderator. A total of 14 SNAP reactors have been constructed to date (Reference 1). Approximately 6 million thermal kilowatt hours have been produced from these reactors to date.

The SNAP 10A reactor constitutes a completely developed and demonstrated design for space flight applications. This system was successfully launched into orbit, started remotely by ground command, and operated in the static control mode at design conditions for 43 days. A failure in the spacecraft electrical system caused inadvertent shutdown of the system. A companion unit, integrated into a complete flight-configured power system, successfully completed 10,000 hours of operation in March, 1966 in a nuclear endurance test under a simulated space vacuum environment. The SNAP 10A reactor power capability is 100 thermal kilowatts at an outlet temperature of about 1100°F. Advancements in fuel element and reflector technology permit operation at outlet temperatures of 1300°F as demonstrated by the SNAP 8 Experimential Reactor during 12,000 hrs of nuclear operation.

If a nuclear reactor electrical power system is to be used in the time period 1970-1980 the AEC (Reference 2) would recommend the UZrH man-rated SNAP 8 reactor. Beyond 1980 a fast reactor utilizing more advanced conversion techniques will hopefully be developed.

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## Thermoelectric Converters

Converters which are considered for use with the SNAP 8 reactor include the Hg Rankine cycle, the Brayton cycle, and the thermoelectric converters. Currently the thermoelectric converter is preferred for a mission such as the manned Mars flyby requiring 5kwe power or more by 1975. This preference was stated to the author by members of the AEC in a recent meeting (Reference 2). The reasons for this preference are briefly discussed. However, it is important to mention that the objective here is to present a power system for consideration for the manned Mars flyby and not to eliminate considerations of other possible system combinations.

The SNAP 2 and SNAP 8 reactors were originally proposed for use with the Hg Rankine cycle as the conversion unit. These programs have been a disappointment because of the cost and time delays involved in developing reliable components for the Hg Rankine cycle. The problems have been well documented in the literature such as Reference 3 and 4. Overall system reliability and maintenance are still the major problems for long duration space power systems of this type.

The problem with a Brayton cycle - SNAP 8 reactor system is the operating temperature. To obtain high performance, 25% efficiency, with the Brayton cycle requires operating the reactor between 1500-1600°F outlet temperature. At these temperatures the life expectancy of the reactor is reduced.

As stated the AEC would prefer to use the thermoelectric converter with the SNAP 8 type reactor. With the Westinghouse compact PbTe converter and SNAP 8 reactor the estimated specific weight is from 2.5 - 3 watts/lb for a 5 - 50kw electrical system (Reference 2). Dr. Wimmer of AI in his paper (Reference 1) discussed a man-rated SNAP 8 reactor-thermoelectric converter system where the power system can be extended from 5 to 20kw electrical. The reactor uses the same core as the SNAP 8 reactor, except that the reflector configuration is optimized to reduce shield weight. Variations of reflector size and number of fuel elements in the core can provide lifetime capabilities of over three years at power levels approaching 900kw thermal. Data on 5, 10, 15, and 20kw electrical power systems discussed by Dr. Wimmer are presented in Table I. The specific power varies from 2.1 to 3.0 watts/lb including shielding.

Thermoelectric power conversion may be accomplished using either silicon-germanium, lead-telluride or segmented silicon-germanium lead-telluride thermoelectric elements. In the SNAP 10A a SiGe direct-radiating converter was used. Over 47 million element-hours of testing were accomplished on these converter modules. Dr. Wimmer (Reference 1) proposed SiGe elements in the man-rated reactor-thermoelectric system described above. Redden and Kitterman AEC propose the Westinghouse PbTe compact converter. Segmenting the two thermoelectric materials SiGe and PbTe is a technique for achieving increased conversion efficiency. Efficiencies of 10% are feasible for a hot-junction temperature of 1700°F and a cold-junction temperature of 80°F (Reference 3). However, the hot-junction temperature of 1700°F is too high for the SNAP 8 reactor.

Conclusion

The demonstrated, operational experience achieved to date with reactor-thermoelectric systems and components is summarized in Table II (Reference 1). On the basis of this experience and design studies of advanced systems utilizing this technology, it is reasonable to conclude that reactor-thermoelectric systems are feasible for the manned Mars flyby mission.

1013-JDD-csh

J. D. Dunlop

Attachments:
Table I and II
References

Copy to
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TABLE I

REACTOR THERMOELECTRIC SYSTEM PERFORMANCE

(5 to 20 kwe)

| | | | | |
|---|---|---|---|---|
| Net Power (kwe) | 5.0 | 10.0 | 15.0 | 20.0 |
| Reactor Power (kwt) | 212 | 424 | 635 | 850 |
| Reactor Outlet Temperature (°F) | 1300 | 1300 | 1300 | 1300 |
| Design Life at Rated Power (yr) | 3 | 3 | 3 | 3 |
| Cross Radiator Area ($ft^2$) | 245 | 525 | 865 | 1150 |
| Base Diameter (ft) | 7.3 | 10.0 | 12.7 | 15.2 |
| Overall Height (ft) | 21 | 31.5 | 41.5 | 50.5 |
| Unshielded System Weight | 1740 | 2885 | 4215 | 5850 |
| Reactor - Payload Separation Distance (ft) | 80 | 100 | 100 | 100 |
| Shield Weight (lb) | 555 | 585 | 620 | 730 |
| Boom and Cable Weight (lb) | 90 | 200 | 225 | 250 |
| Total Shielded System Weight | 2385 | 3670 | 5060 | 6830 |
| Specific Power (watt/lb) | 2.1 | 2.7 | 3.0 | 2.9 |

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TABLE II

REACTOR-THERMOELECTRIC SYSTEM TECHNOLOGY SUMMARY

| | | |
|---|---|---|
| Reactors | 6 million kwh nuclear operation (SNAP 10A, 2, and 8)<br>10,000-hr demonstrated endurance; 40 kwt, 1000°F (SNAP 10A)<br>1 yr at 400 to 600 kwt, $\geq$ 1300°F (SNAP 8) | |
| TE Converters | 47 million element hours (1000°F)<br>30,000-hr demonstrated endurance | SNAP 10A Converters |
| | > 1.2 million element hours at $T_{max} \geq 1300$°F<br>> 14,000-hr demonstrated endurance at $T_{max} \geq 1300$°F<br>5-yr equivalent endurance at 1300°F (accelerated high temperature tests) | Advanced SNAP 10A Type Converters |
| EM Pumps | 200,000-hr total operation, 20,000-hr demonstrated endurance | |
| Complete Space Power Systems | 10,000-hr demonstrated endurance (SNAP 10A ground test) plus successful orbital startup and operation of SNAP 10A in space. | |

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## REFERENCES


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5. D. E. Treas, and J. J. Mueller, "Silicon-Germanium Lead-Telluride Segmenting for Improved Thermoelectric Efficiency", Proceeding Thermoelectric Specialists Conference, May 17-19, 1966.